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Neuroethology and the Philosophy of Cognitive Science

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Neuroethology is a branch of biology that studies the neural basis of naturally occurring animal behavior. This science, particularly a recent program called *computational neuroethology*, has a similar structure to the interdisciplinary endeavor of cognitive science. I argue that it would be fruitful to conceive of cognitive science as the computational neuroethology of humans. However, there are important differences between the two sciences, including the fact that neuroethology is much more comparative in its perspective. Neuroethology is a biological science and as such, evolution is a central notion. Its target organisms are studied in the context of their evolutionary history. The central goal of this paper is to argue that cognitive science can and ought to be more comparative in its approach to cognitive phenomena in humans. I show how the domain of cognitive phenomena can be divided up into four different classes, individuated by the relative phylogenetic uniqueness of the behavior. I then describe how comparative evidence can enrich our understanding in each of these different arenas.

1. Introduction. There are a variety of opinions concerning the relationship between psychological and neurobiological levels of explanation. I side with those who argue that understanding systems as complex as intelligent systems seem to be is hard enough without turning a blind eye on one source of information or another. I have come to this opinion by consid-

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ering the science of neuroethology, wherein scientists studying so-called "simple" vertebrate and invertebrate organisms have found it necessary to work at many levels at once. Their work suggests that coming to a full understanding at *any one* level of explanation requires input and scrutiny from *many* levels. Neurobiology, evolutionary biology, and the study of behavior all play off of one another in the understanding of animal behavior. There seems no good reason to think things will be easier for cognitive science (CogSci).

The conclusion of this paper is that a comparative approach to the questions of CogSci can further its goals of understanding the nature of intelligent behavior. My reason for saying this is that the biological science of computational neuroethology (CNE) pursues much the same goals with respect to nonhuman animals, and comparative evidence has played a central role in that science's approach to its related questions. The related goals of CogSci and CNE provide a *prima facie* motivation to investigate whether comparative evidence can do for CogSci what it has done and continues to do for CNE. In this paper, I explore the implications of the analogy that, traditionally construed, neuroethology is to nonhuman animals what CogSci is to humans. In particular, I want to explore the possibility of refashioning contemporary CogSci in the image of neuroethology; to explore the possibility of a neuroethology of cognitive behavior, in both human and nonhuman animals.

This paper has two main parts. In Section 2 I introduce the science of neuroethology. Then, I turn to the area of greatest difference between this science and CogSci as it is traditionally construed: More so than CogSci, neuroethology is explicitly *comparative* in its approach. The evolutionary history of its subjects plays a much larger role than the evolutionary history of humans does in CogSci. I argue that CogSci ought to be more comparative in its approach and outline the various ways in which comparative research can inform CogSci.

2. What is Computational Neuroethology? Coined independently by Randall Beer (1990), Dave Cliff (1991a, b; 1995), and Walter Heiligenberg (1991), *computational neuroethology* (CNE) conjoins contemporary computational techniques (computational modeling, robotics, etc.) with the traditional concerns of neuroethology. *Ethology* is the study of animal behavior in natural contexts; for example, the study of electric fish social behavior in the lowland streams of Panama and in ecologically valid laboratory settings. *Neuroethology* is the study of the neural basis of animal behavior; for example, the study of how an electric fish nervous system enables the organism to perceive electrical stimuli. *Computational neuroethology* is the application of contemporary computational modeling methods and concepts to neuroethology. The work is "computational" in

two senses. First, these neuroethologists sometimes build robotic and computational models of animal behavior. Second, they often theoretically model organisms as computational systems, i.e., as systems which carry out computations over representations.

More formally, we can identify several distinctive features of CNE:¹

Domain: The domain of neuroethological inquiry is all aspects of naturally occurring animal behavior. This includes the adaptive character of behavior, both to the individual organism and to the species. Neuroethologists want to know why animals behave the way they do; they want to understand the function of behavior. This desire to discover the appropriate way to characterize behavior—to understand its function—is central to CNE.

However, beyond characterizing behavior, neuroethologists wish to understand how the behavior they characterize is brought about in individual organisms. The “neuro-” in neuroethology points to the goal of understanding the neural basis—the proximal cause—of naturally occurring animal behavior (Tinbergen 1963). These twin foci—the characterization of behavior and neural mechanisms of its production—are independent but related. The same behavior (i.e., behavior with the same adaptive value to an organism) can be produced by different mechanisms in different organisms. At the same time, the same mechanism can be put to different uses in different animals. Furthermore, in practice, the understanding of mechanisms and behaviors goes hand in hand. There are numerous examples in neuroethology in which the characterization of a behavior has been influenced by discoveries about mechanism of its production, as well as examples of the opposite direction of influence.

Techniques: CNE cannot usefully be defined by reference to any widely used set of experimental and analytical techniques. CNE is remarkable for its openness to practically any kind of technique which might reasonably be expected to shed light on the nature of animal behavior. A survey of neuroethological laboratories and neuroethological publications will reveal a plethora of approaches. In the same lab, one might expect to find scientists pursuing single-cell recording, immunohistochemistry, mitochondrial DNA analysis, field studies, numerical modeling, etc.

Theories and Explanation: Neuroethologists constantly struggle to reconcile two, often competing, desires: breadth and integration. It has been said that neuroethologists “collect stories like winos collect cigarette butts.” These stories are wide-ranging in a variety of ways. They range

1. The present discussion concerns what computational neuroethology *is*. For a more detailed discussion of how CNE *works*, in a particular case, see Keeley 1999. Section 3 of that paper discusses how the various subfields of neuroethology cross-constrain one another in the process of hypothesis confirmation.

across the animal kingdom, from leeches and lobsters to moles and monkeys. It is relatively rare to find two laboratories or even two neuroethologists working on exactly the same species. For example, among the handful of laboratories around the world dedicated to the study of electric fish, each generally takes a different species as its primary animal of study, although there often is overlap in the secondary animals of study.

The collected stories of neuroethology also range over levels of analysis and types of behavior. The discussion of techniques above suggests the range of levels neuroethologists cover. Neuroethological investigation covers the gamut from neurotransmitter molecules to the behavioral ecology of entire species to formal models of communication. Finally, there seems to be no *a priori* limitation on the types of behavior open to investigation. One can find studies of feeding behavior, mate selection and courtship, nest building, behavior associated with active perception, predation and anti-predation behavior, and so on.

At the same time, neuroethologists are actively concerned not to be mere "stamp collectors." The goal of neuroethology is not simply to collect an enormous number of disconnected examples illustrating the wonderful diversity of nature. The collected stories are related because the animals those stories are about are themselves related. Perhaps the key insight of the founders of ethology, particularly Konrad Lorenz, is that animal behavior can reveal evolutionary relationships. Behavior in related animals, particularly subtle differences in behavior between ostensibly related species, is just as revealing as other characters—bone anatomy, for example. The comparison of neural characters and other aspects of behavioral mechanisms are also used to understand how animals are evolutionarily related.

Neuroethologists are not solely interested in evolutionary relationships. Many animals live in very similar ecological niches, and this similarity is studied as a unifying leitmotif of neuroethological stories. How one animal adaptively responds to life in a particular niche often turns out to be related to how other animals have responded to life in a similar or related niche. At the very least, it gives one a useful starting point with which to explore the behavior of the new animal. So, for example, neuroethologists look for similarities in the electrical behaviors and mechanisms of African and New World weakly electric fishes, even though those two lineages of fish evolved their electrical capacities independent of one another. Nonetheless, many of the principles of electroreception and bioelectrogenesis are the same or very similar in species of the two orders of fish.

Animals might share a close phylogenetic connection, or a similar ecological niche and resulting collection of adaptive behaviors. In addition to these, they might also share related mechanisms, even when the ultimate function of these mechanisms is very different. At first blush, one might

think that echolocation in bats has little or nothing to do with electroreception in weakly electric fish. This initial impression would be wrong, because it turns out that both functions (echolocation and electroreception) are carried out in the animals in a way that requires the ability to make extremely fine temporal comparisons. Echolocation in the bat requires comparing extremely tiny interaural time differences between auditory signals hitting the two ears. Electroreception in weakly electric fish requires comparing minute temporal differences between signals detected at different locations on its body. Moreover, the neural circuits that carry out these comparisons in these two animals share many common features, a fact that is not too surprising given the similarity of their functions.

In sum, we can characterize computational neuroethology as the study of naturally occurring animal behavior along with the mechanisms of its production. The techniques of investigation are wide-ranging and there seem to be no *a priori* limits on what techniques are available to the neuroethologist. In terms of explanatory goals, computational neuroethology seeks to explain a wide range of animal behavior from a variety of levels of inquiry, but at the same time there is a desire to integrate these explanations by calling on properties shared by these varied organisms, be it evolutionary relationship, similar lifestyle and ecological niche, and/or shared mechanisms of behavior production.

3. What is the Relationship between CNE and CogSci? Computational neuroethology brings together a variety of different approaches to the study of animal behavior: 1) the neural sciences, i.e., neurophysiology, neuroanatomy, neuropharmacology, etc.—the study of the structures and processes that mediate behavior; 2) ethology—the study of naturally occurring animal behavior, both “in the wild” and in the laboratory; 3) evolutionary biology—the study of the phylogeny of animal behavior and the structures which mediate it; 4) developmental biology—the ontogeny of animal behavior and the structures which mediate it; and 5) computational modeling—building robotic and computer simulations of animal behavior; to name the most significant constituents.² Bullock (1990) gives some idea of the broad scope of neuroethology:

In the broad sense in which it is generally used today, neuroethology

2. There is a good deal of discussion within neuroethology as to its proper scope, and I am explicitly siding with those who give it a broad rather than a narrow reading. For instance, one of the most vocal proponents for a limited scope for neuroethology is Graham Hoyle (cf. Hoyle 1984) who argues that it would be best if neuroethology restricted itself to the explanation of innate behaviors in terms of single, identified cells. Hoyle's proposal has generated more controversy than consensus. See the responses to Hoyle 1984 printed in the same issue, particularly Bullock 1984.

includes studies on protozoans and humans, reflexes and cognition, ion channels and brain/body ratios, learning in snails, and the innate understanding of squirrel monkey calls by squirrel monkeys . . . Neuroethology is not only concerned with causation and function. For example, how does echolocation work in terms of neurons? It is also concerned with development and evolution, in terms of molecules, motor control, and mental events. The field is inevitably both reductionist and integrative, both comparative and general, though usually not in the same study. (244)

Computational neuroethology and CogSci share many affinities. First, they both ask many of the same questions about mechanisms and behavior, but where neuroethology asks those questions of all animals, CogSci focuses primarily on humans. Second, both are highly interdisciplinary, and feature a very similar constitutive structure; neurobiology and computational modeling play much the same role in each science. The contribution of developmental biology to neuroethology is analogous to the contribution of developmental cognitive psychology to CogSci. Ethology's focus on naturally-occurring behavior mirrors anthropology's focus on natural human instances of cognition, e.g., Hutchins 1995. Ethology's focus on laboratory studies of the behavioral capacities of animals is reflected in psychology's focus on the behavioral capacities of humans under controlled laboratory conditions. Finally, while philosophy may play a much more visible role in CogSci, it also plays a role in CNE.

There is (at least) one glaring obstacle to my attempt to refashion CogSci in light of computational neuroethology. While both neuroethology and CogSci make roles for neuroscience, computational modeling, philosophy and the study of natural behavior (ethology in neuroethology; psychology in CogSci), there is a mismatch with respect to the role played by comparative, or evolutionary, biology. The evolution of behavior and the structures that mediate it play a central role in neuroethology, but plays little or no role in CogSci. In order to make my case for CogSci as the computational neuroethology of humans, I need to make a case for the role of evolutionary biology in the study of cognition.

Evolutionary biologists seek to understand how life as we currently know it has evolved from life as it once was. A comparative methodology consists in the attempt to reconstruct the phylogenetic relationships between extant species of organisms. More importantly, it involves using phylogenetic relationships to make predictions about the traits of animals that have yet to be studied. This is the primary contribution of comparative work. When you know something about an organism—say, that it generates some kind of a behavior in a particular way—and you know something about its evolutionary relationship to other organisms, you

automatically have a hypothesis about those other organisms: namely, that they generate that same kind of behavior in the same way and that similarities can be sought in ontogeny, morphology, physiology, etc. When dealing with complex nervous systems capable of carrying out complicated behaviors, this educated guesswork can be a valuable hint in the right direction.

4. Objections to a Comparative Approach to CogSci. There are several possible objections to the claim that CogSci ought to focus more attention on the comparative biology of cognition. The first objection is that most of the phenomena of interest to CogSci are too uniquely human to be open to comparative analysis (cf., Washburn and Dolhinow 1983, Gopnik 1996). According to this line of argument, language, formal problem-solving, reading, and the like are behaviors that only humans exhibit. All other species lack these traits. Comparative methods cannot “get a grip” on that which most interests CogSci. It may make sense to study electroreception in a comparative context because there are a relatively large number of electroreceptive species, each of which exhibits this sensory modality in its own specific way. However, *Homo sapiens* is the only species that reads. There are no other species that read with which to compare humans.

A second objection follows from the first: Even those phenomena which are shared with other organisms—navigation in humans and insects, social behavior in humans and fish—are not (*prima facie*) closely related in the phylogenetic sense. Human navigation skills most likely did not evolve from the navigation skills of the common ancestor of ants and humans, so it is unclear, at best, what a comparative study of the two could ever tell us.

In response to such objections, we should first point out that they presume a nontrivial degree of comparative knowledge in the first place. We cannot identify any given trait as “uniquely human” until we have done enough comparative work to reasonably conclude that these traits are, in fact, uniquely human. Second, throughout this paper, I will assume that the continuity of species and their behavior that we find in the biological world calls for a *continuity of explanation* of that behavior. We ought to expect that the explanations we give of human behaviors have *some* connection to the explanations we give of nonhuman animal behavior.³

3. Churchland and Churchland (1983, 8) note that, “Representations—information-bearing structures—did not emerge of a sudden with the evolution of verbally competent animals. As Sellars remarks, ‘the generic concept of a representation admits of many gradations between primitive systems and the sophisticated systems on which philosophers tend to concentrate.’ Whatever information-bearing structures humans enjoy, such structures evolved from simpler structures, and such structures are part of a *system* of information-bearing structures and structure-manipulating processes. If we

I am not denying that there are uniquely human traits. There surely are, as every species is, by nature, unique (Foley 1987). Furthermore, it is very likely that human behavior (and the big brain that mediates that behavior) plays a large role in making humans unique. Nevertheless, in order to understand what makes us uniquely human, we must study and understand the often subtle distinctions that separate us from the rest of the animal world. This is simply analytic. Uniqueness, just like "similarity" and "identity," is a relation between entities. To say that one species is unique in a particular way is to make a claim about the properties of both that species and all other species. This understanding is exactly what comparative research seeks.

It would help the present discussion to do a little conceptual analysis of traits and their phylogenetic standings. Consider x , a trait of interest to CogSci. Presumably, x is a trait that is possessed by humans, otherwise it would not be of interest. Now this trait will either be present in other species or it will be absent. If x is absent in all other species, I will call this trait "unique" to humans, and we will turn to it again in a moment. If x is shared with other species, then we must next ask what the probable evolutionary relationship is between humans and that other species with respect to that trait. Again, there are two possibilities. If the trait is likely to be one that is derived from the common ancestor of humans and the other animal(s), we will call the trait "homologous." If, on the other hand, it is unlikely that humans and this animal share a common ancestor that itself had the trait in question, then this trait is "analogous." (An analogous trait is therefore a product of convergent evolution.) Returning again to uniquely human traits, we must ask whether this trait stands in some continuous relationship to traits possessed by closely related species. We must ask, in other words, does this uniquely human trait look like any other related trait in our closest phylogenetic relatives or is it truly a unique human invention? If the former, then call the trait "unique and continuous." If the latter, then call the trait "unique and discontinuous." Therefore, on the analysis I am offering here, human traits of interest to CogSci fall into four categories: homologous, analogous, unique and continuous, and unique and discontinuous. My reason for dividing up the space of possibilities this way is that I will argue that comparative biology has a *different* potential contribution to CogSci in each of these classes of traits. Comparative evidence has a role to play in each of these categories, although it is a different role in each. Therefore, I will discuss them separately.

want to understand how epistemic engines work, we might have to understand simpler systems first, and that means we cannot avoid penetrating the skull, implanting electrodes, and looking nature full in the face."

1) *homologous* A homologous trait is one that is shared by two organisms and the most recent common ancestor of those two organisms. At least some of the traits that CogSci studies are homologous with those in other, closely related organisms. For example, the human visual system—the study of which is a mainstay of CogSci—is to a large degree homologous with that of nonhuman primates.

If a certain trait is homologous in humans and some nonhuman animal, then that trait can be studied in the nonhuman animal with a good degree of confidence that any findings will apply to humans as well. This is useful for several reasons. First, there are experiments we can perform on nonhuman animals that would be technically difficult or ethically problematic to carry out on human subjects. Single-cell recording in the visual cortex is a good example. The ethical difficulties of drilling holes in people's heads and inserting recording electrodes can probably go without comment. Also, monkey brains are in many ways just easier to work with, from a technical perspective. The increased folding of the surface of the cortex in humans, as opposed to the less folded cortical surface in monkeys, renders certain brain regions in the visual cortex relatively more accessible in monkeys. In other words, sometimes it is technically much easier to perform neurophysiological studies on nonhuman primates than on humans.

Therefore, the study of homologous systems, such as the visual system, in nonhuman animals, e.g., monkeys, can provide insight into human issues by virtue of the fact that these processes are carried out in similar ways in both humans and monkeys. This similarity is true by virtue of our recent shared ancestry. This is not to say that there are no differences between primate visual systems, indeed it is the differences that in many ways make monkeys easier to work with. So, for example, the function and synaptic structure of Area V1 may be homologous in macaques and humans, but its location in the brain may not be. Knowledge of these differences is crucial to further our understanding of what facts learned about monkey visual processing can be transferred to humans. Hence, the importance of work such as that done by Sereno et al. (1995), who are using modeling and functional imaging data to map the locational and functional correspondences between visual areas of the cortex in a variety of primate species.⁴

2) *analogous* An analogous trait is one that is shared by two organisms,

4. The prominent role of such work in CogSci might indicate to some that the argument of this section is a *fait accompli*; that such work shows that CogSci *is* comparative. To those of this sentiment, I would ask that you read this section as an argument that CogSci should be *more* comparative. I would also remind the reader that my motivation for pursuing the present line of argument is to justify the role of comparative biology in CogSci. If one is prepared to accept that role, then that is one less obstacle in the way of seeing the potential application of CNE to CogSci.

but which did not evolve from a common ancestor with that same trait. We say that analogous traits are the product of convergent evolution. For example, neuroethologist Rüdiger Wehner and his colleagues (1983) have spent several decades describing the incredible navigation abilities of the Saharan desert ant, *Cataglyphis bicolor*, an animal capable of remembering the location of its nest even as it travels several meters from home pursuing a random-walk search for food. However, even if some aspects of navigation in humans and Saharan desert ants are significantly similar, such a trait is undoubtedly analogous. It is unlikely that the extremely distant common ancestor of *Homo sapiens* and *Cataglyphis bicolor* possessed a similar trait from which the contemporary trait has evolved in both species.

What can the study of analogous traits in nonhuman animals tell us about that trait in humans? First, studying an analogous trait often tells us as much about the trait itself as about the organisms that possess it. This is relevant because CogSci is interested not only in explaining human capacities, but also in exploring the design space of mechanisms capable of generating those capacities.⁵ In this way, cognitive scientists interested in navigation behaviors in general should be interested in the unique, non-human mechanisms for skilled navigation in Saharan desert ants. These animals represent a successful and exquisite solution to the “navigation problem,” and as such they occupy an interesting spot in the design space.

Finally, studying analogous traits in other, simpler organisms forces us to be clearer when assessing our theories of those traits. If we claim that a behavior requires *x*, e.g., structures or processes with particular properties, then we have an expectation of finding *x* in a simpler organism. So, on the comparison of human and ant navigation strategies, Wehner (1983) notes, “In understanding how humans go about similar problems we are often hamstrung by the intuitive belief that our solutions are trivially obvious. Thus, there is heuristic value in studying such problems in other than human beings, and even in animals as small as insects” (366). So, for example, cognitive scientists interested in artificial intelligence and robotics would, therefore, do well to explore the variety of natural solutions to such problems as autonomous navigation.⁶

3) *unique and continuous* Some traits may well turn out to be unique to

5. Consider, for example, the recent speculation concerning the human predilection for sweet and fatty foods, even though such a diet proves detrimental for most contemporary members of our species. Understanding that the nature of human appetites evolved in a period of history when such fatty foods were scarce and hard to acquire goes some way towards explaining our now dangerous tastes in foods (Eaton et al. 1997).

6. See Eibl-Eibesfeldt 1983 for more on the benefits of studying analogous traits, particularly with respect to humans.

humans. However, of these uniquely human traits, some will nonetheless be evolutionarily continuous with traits in other species. For example, humans are nature's foremost theorists about minds. We are highly social and spend a great deal of our lives trying to figure out what our conspecifics know and desire; what they are thinking and planning. However, even to the extent that our capacity to reason about the minds of others and ourselves is unsurpassed, this capacity is clearly continuous with the capacities of nonhuman primates. This continuity is the basis of a currently prolific area of research in cognitive ethology (e.g., Premack and Woodruff 1978, Povinelli and Preuss 1995, Whiten 1991, Carruthers and Smith 1996). The evidence to date seems to be that while humans reason about other minds to a significant extent, many nonhuman animals reason less deeply about their conspecifics. The difference between theory of mind in humans and nonhumans is one of degree, not of kind.

Neuroethology has traditionally taken as its paradigm cases, unique and extraordinary animal systems which are arguably the best at some capacity. So, because bats and owls have the most developed auditory systems, neuroethologists have chosen to study these animals as a way to understand the nature of audition. Heiligenberg explicitly endorses this approach and enumerates its rationale, noting that

some animal species are champions in particular aspects of sensory or motor performance and . . . such superior capabilities are linked to highly specialized neuronal structures. Such structures incorporate and optimize particular neuronal designs that may be less conspicuous in organisms lacking these superior capabilities. Moreover, the behavioral repertoire of such "champion" species readily offers paradigms for testing the performance of their special designs at the level of the intact animal. Electric fish and echolocating bats, for example, are masters in the processing of temporal information and show an abundance of mechanisms devoted to the analysis of temporal signal characteristics. Therefore, these animals provide powerful model systems for behavioral as well as cellular studies of a wide scope of neural mechanisms dedicated to temporal information processing. Their exploration will reveal the diversity and limitations of these mechanisms and should ultimately facilitate our understanding of temporal information processing in other systems, for example, speech perception in humans. (1991, 2, see also Carr 1993)

Seen from the perspective of neuroethology, human cognitive capacities can be seen as just another animal system. If we want to understand the capacity to reason about minds, then it makes sense, the neuroethologist argues, to study that organism which is renowned for its skills of reasoning about minds, in this case, humans. As Heiligenberg notes, the study of

such an animal system is likely to reveal the limitations of such mechanisms and provide an arena for testing hypotheses about these types of mechanisms.

4) *unique and discontinuous* The final category of traits contains those which are both unique to a particular species of organism and so different from all other traits that it is impossible to establish a continuous set of extant stages between that trait and others. A potential example of this kind of trait in humans is the grammaticality of human language, a trait which is arguably so different from the grammaticality of nonhuman communication that it has become, for some, the last refuge of those who wish to establish the unique prowess of *Homo sapiens*. Even clearer examples are the human capacities for written language and complexly articulated speech, neither of which have clear counterparts in any other extant species.

The best argument that the study of nonhuman animals can teach us something about such traits derives from the conservative nature of natural selection. If comparative biology has shown us anything, it is that it is very rare indeed that organisms create new traits out of whole cloth. More often than not, a new behavioral trait results from the novel application of an old mechanism. Nowhere is this more true than in nervous systems, in which old structures are continually being put to new purposes. That is to say, unique evolutionary adaptations are often carried out by homologous brain structures. This is relevant because the brain is not behaviorally flexible in the way, say, a computer is. You cannot simply erase the memory of a brain area and upload a new program that carries out some completely different task. There are structural constraints on the behavioral capacities brain regions can carry out, including, but not restricted to, the speed at which neurons can operate, the nature of their connections both upstream and downstream, and the nature of their constituent cell-types.

Therefore, even if we accept that humans are the only animals that read and write, or that have a highly developed grammar, we should ask what neural structures are mediating these behavioral properties. What are apes and monkeys doing with the parts of their brains which in humans are subserving grammar and reading? To date, nobody has identified a cortical area that only humans have, so humans have likely evolved new ways of using brain areas that apes and monkeys are using for something else. For example, did humans take over brain areas for executing fine-grained motor movements and put them to use controlling our complex vocal apparatus? If so, then drugs that affect perseverative behaviors in monkeys might be useful in treating human stuttering.

5. Conclusion. In the discussion above, I have focused on the value of discovering similarities between human brains and cognition and the

brains and behavior of nonhuman animals. My argument to this point has been that comparative approach can shed light on such similarities, but it is important to keep in mind that it can also give us insight into the differences between humans and the rest of animal kingdom. Surely these differences are of interest to the cognitive scientist. Take for example the oft-repeated, but rarely cited, fact that humans and chimpanzees have genomes which are 98% identical.⁷ That 2% difference, together with the difference between human and chimpanzee developmental environments, must account for all the differences between the two species.

What is the difference between the brains of humans and chimpanzees that accounts for our different cognitive capacities? (Note that this is a question best posed after we have a comparative understanding of exactly what those differences are.) An understanding of the cognitive nature of humans will be incomplete if it does not include an explanation of how we humans are different from closely related species who happen to have very similar-seeming brains.⁸

The point of this paper is to remove one of the major obstacles to refashioning CogSci in the light of CNE: the comparative nature of CNE and the noncomparative nature of traditional CogSci. Specifically, I have shown the numerous ways which comparative biology can inform CogSci investigations. In doing so, I have shown that one of the most obvious differences between the approaches of CNE and traditional CogSci can be overcome.

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7. Goodman 1992, e.g., argues that there is a 98.4% degree of similarity between the DNA nucleotide sequences in the genera *Homo* and *Pan*.

8. The importance of studying differences has been made clear to me by Ted Bullock (cf., in particular, Bullock 1993, Ch. 1).

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